In the News

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Heart-Device Hacking Risks Seen

By KEITH J. WINSTEIN
March 12, 2008; Page D7

Medical devices that control the human heart may need safeguards to protect against remote-control hacking that could deliver electrical shocks to patients, researchers said.

Millions of Americans have pacemakers, which keeps hearts beating regularly, or an implanted defibrillator, which can restart stopped hearts with an electric jolt. After implanting a defibrillator under a patient's skin, a doctor uses a special device, about the size of a breadbox, to tell the defibrillator what to do -- for example, to instruct it to keep the heart beating at a certain rate or deliver a test jolt.

The devices, called programmers, communicate with a defibrillator using radio waves. To prevent tampering, only physicians are allowed to buy one from the manufacturers -- Medtronic Inc., Boston Scientific Corp., and St. Jude Medical Inc.

But hackers could transmit the same radio signals -- causing a defibrillator to shock or shut down, or divulge a patient's medical information -- without needing a programmer, researchers found in a laboratory test of one model from Medtronic.

Opportunities for Fidelity-Energy Minimization in Body Area Networks: A Communications Perspective

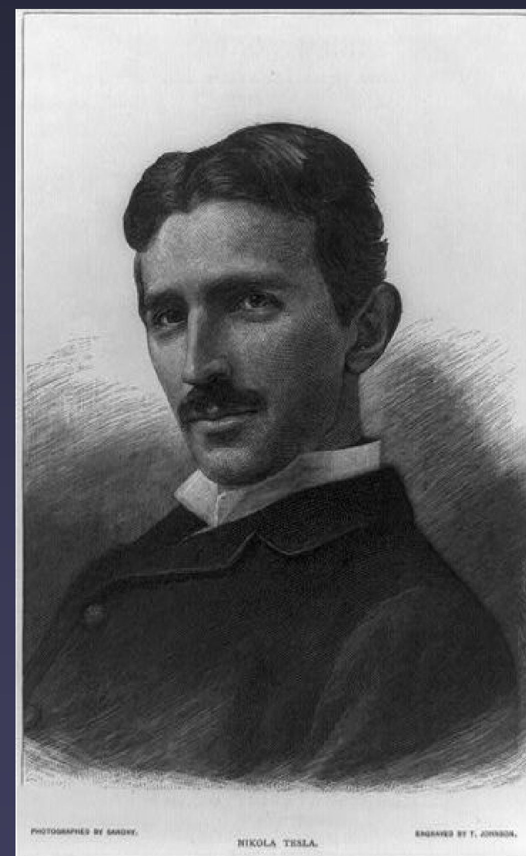
Mark Hanson

Getting Started: RF-BANs

"The scientists of today think deeply instead of clearly. One must be sane to think clearly, but one can think deeply and be quite insane."

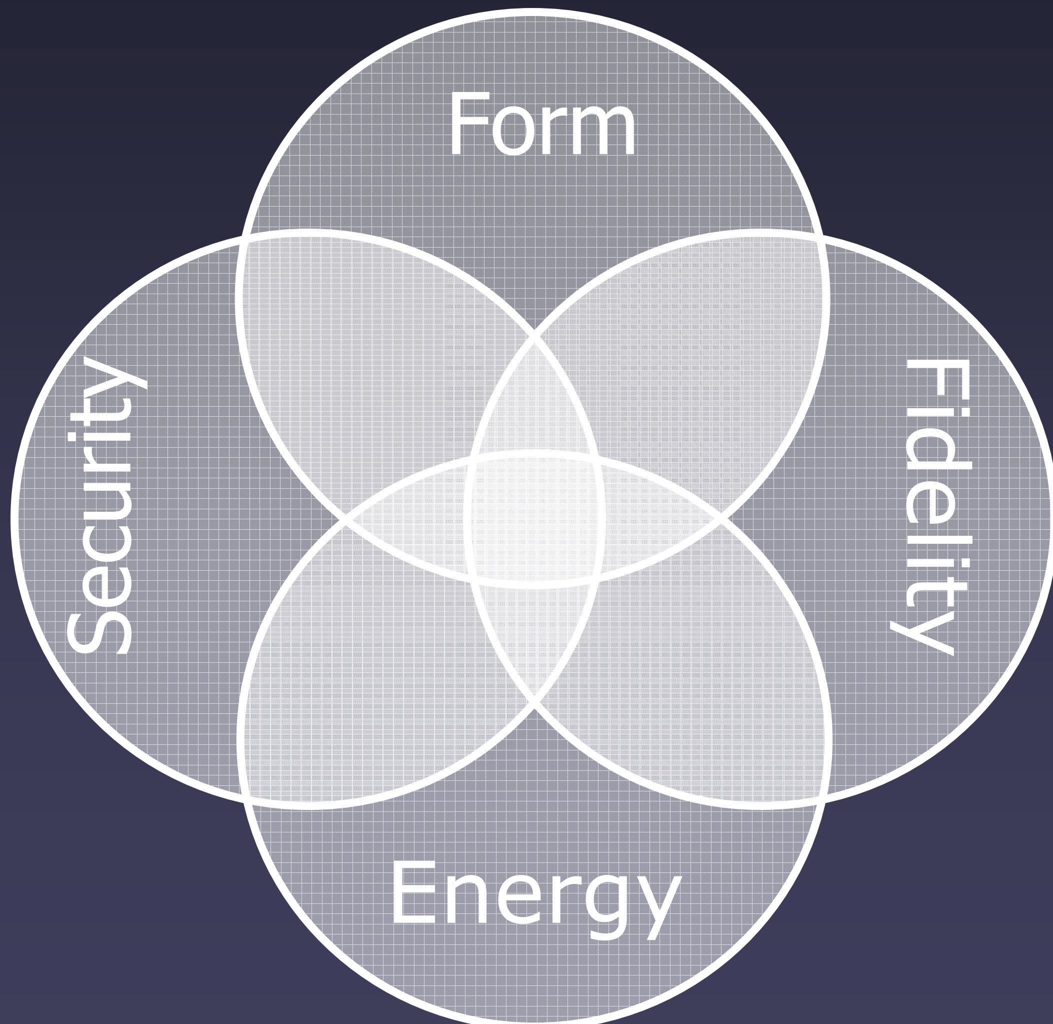
~ N. Tesla

Nikola Tesla [1]



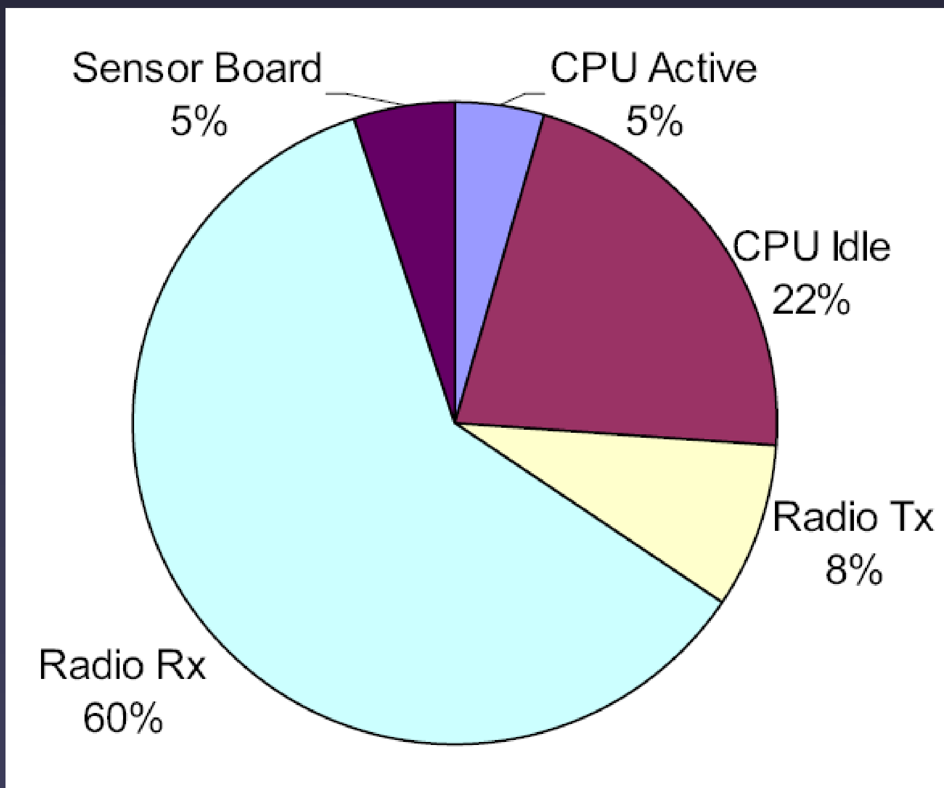
1) Image from the Library of Congress (loc.gov)

What's Important in RF-BANs?



So where should we start?

Energy Profile Using AEON [2]



MICA2 Mote [1]

MICA2 Power Model [2]

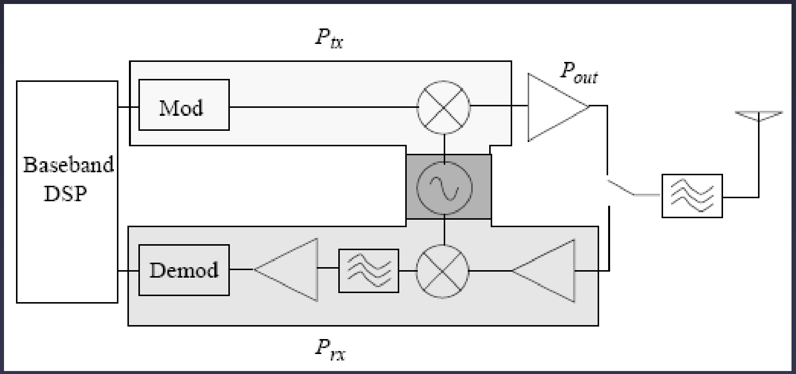
Device	Current	Device	Current
CPU		**Radio** (900 MHz)	
Active	7.6 mA	Core	60 μA
Idle	3.3 mA	Bias	1.38 mA
ADC Noise	1.0 mA	Rx	9.6 mA
Power down	116 μA	Tx (-18 dBm)	8.8 mA
Power Save	124 μA	Tx (-13 dBm)	9.8 mA
Standby	237 μA	Tx (-10 dBm)	10.4 mA
Ext Standby	243 μA	Tx (-6 dBm)	11.3 mA
		Tx (-2 dBm)	15.6 mA
LED (each)	2.2 mA	Tx (0 dBm)	17.0 mA
		Tx (+3 dBm)	20.2 mA
Sensor Board	0.7 mA	Tx (+4 dBm)	22.5 mA
		Tx (+5 dBm)	26.9 mA

1) Image from the Crossbow Corporation (xbow.com)
2) O. Landsiedel, K. Wehrle, S. Rieche, S. Gotz, and L. Petrak, "Accurate prediction of power consumption in sensor networks," IEEE Workshop on Embedded Networked Sensors, pp 37-44, 2005.

Radio Woes

- Observation: The radio is consuming a large proportion of the energy in sensor nodes.
- Question: What are the implications?
- Question: What can be done?

A Radio Model [1]



Average Radio Power Consumption [1]

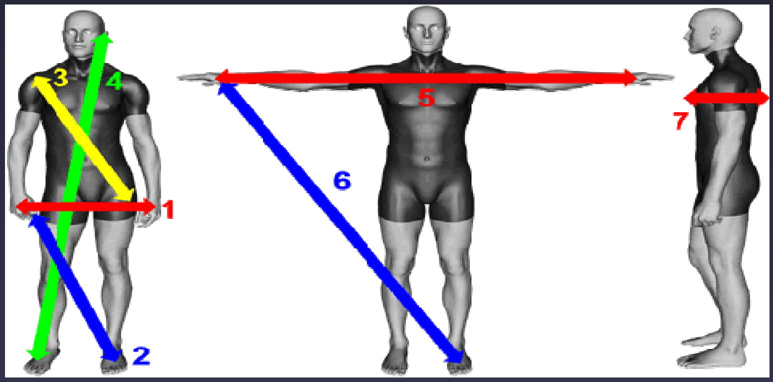
$$P_{radio} = N_{tx}[P_{tx}(T_{on-tx} + T_{st}) + P_{out}T_{on-tx}] + N_{rx}[P_{rx}(T_{on-rx} + T_{st})]$$

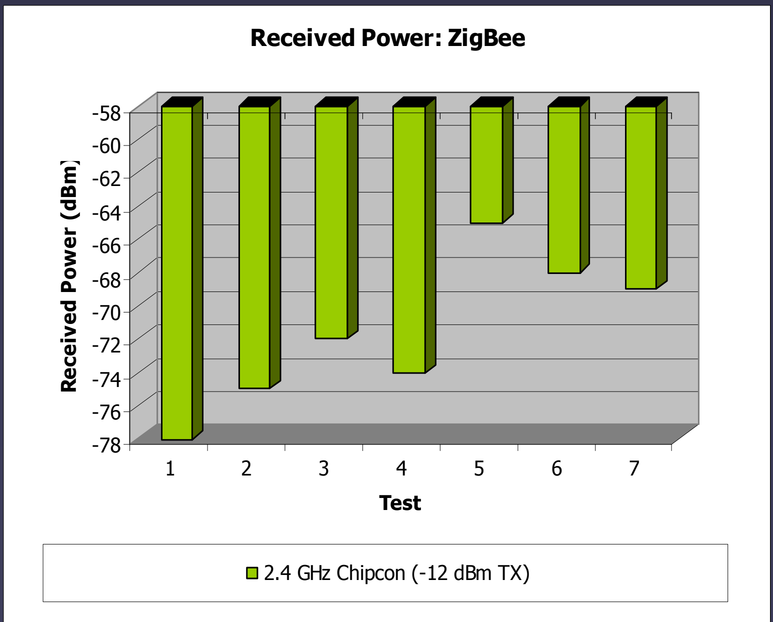
1) E. Shih, S. Cho, N. Ickes, R. Min, A. Sinha, A. Wang, A. Chandrakasan, "Physical layer driven protocol and algorithm design for energy efficient wireless sensor networks," ACM SIGMOBILE, pp 272-286, 2001.

Body-Area Channel Woes

- The body poses major challenges for low-power, reliable communication
- At 2.4 GHz, there is significant attenuation due to the body
- Sensor placement causes received signal strength to fluctuate due to variability of path loss

Attenuation Due to Sensor Placement [1]

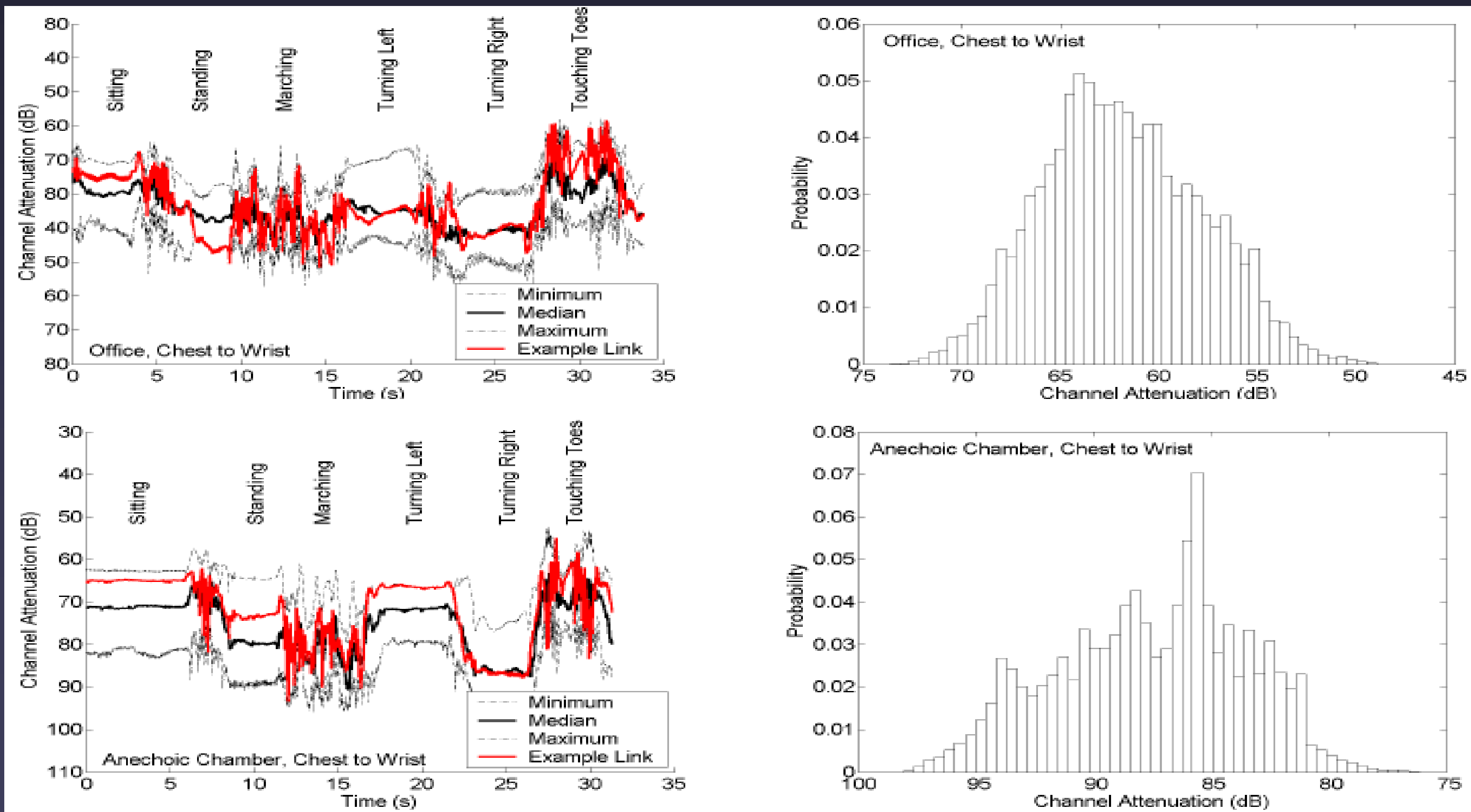




1) A.T. Barth, M.A. Hanson, H.C. Powell Jr., D. Unluer, S.G. Wilson, J. Lach, "Body-coupled communication for body sensor networks," International Conference on body area networks, accepted for publication, 2008.

More Body-Area Channel Woes

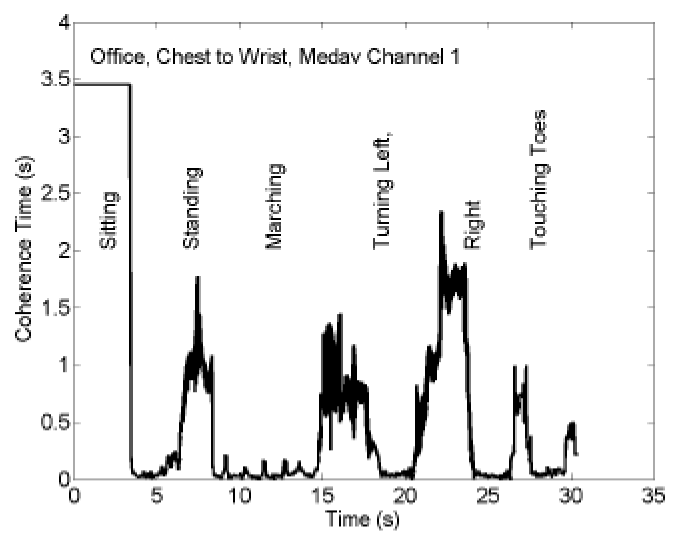
Attenuation Due to Body Movement [1]

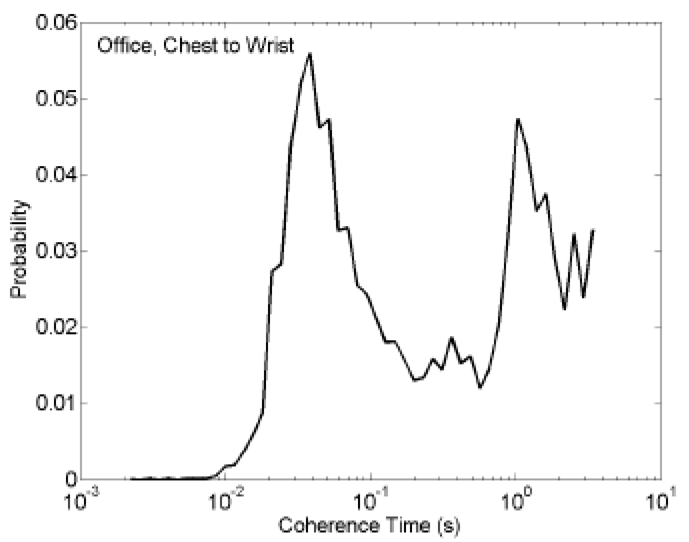


1) D. Neirynck, "Channel Characterisation and Physical Layer Analysis for Body and Personal Area Network Development," Doctoral Dissertation, University of Bristol, 2006.

More Body-Area Wireless Woes

Channel Coherence Time During to Body Movement [1]





- Observation: A moving body can cause the channel characteristics can change over time.
- Question: What are the implications?
- Question: What can be done?

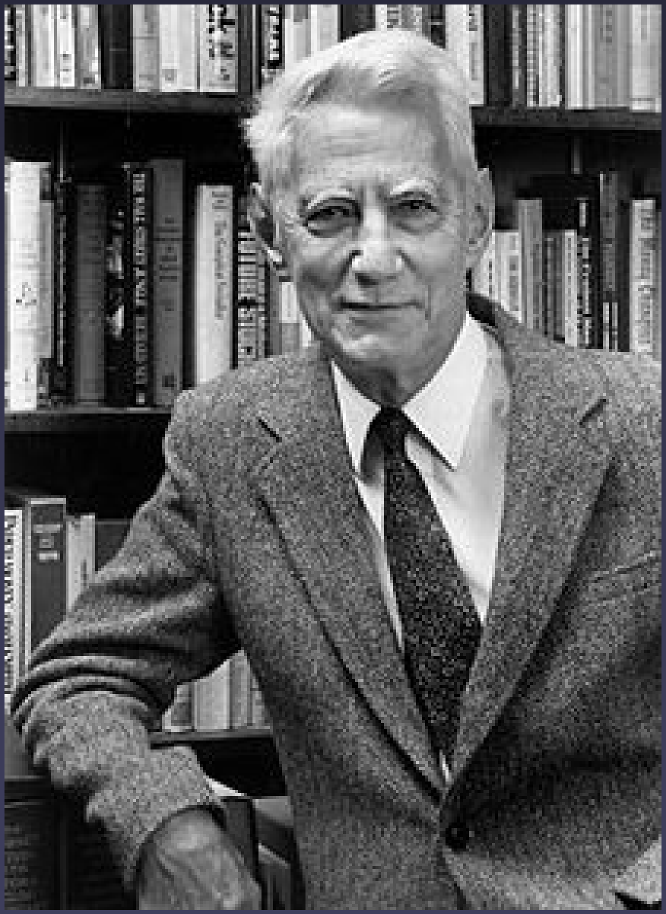
1) D. Neirynck, "Channel Characterisation and Physical layer analysis for body and personal area network development," Doctoral Dissertation, University of Bristol, 2006.

Quick Detour: Information Theory

"Information is the resolution of uncertainty."

~ C.E. Shannon

Claude Shannon [1]



1) Image from of Bell Labs (bell-labs.com)

Source Coding Theorem [1]

- Motivation:
  - Signals generated from physical sources contain redundant information
  - Efficient transmission of signals requires purposeful removal of redundancy
- Source Coding Theorem [1]
  - Average code word length for a distortionless source-encoding scheme is bounded by the source entropy

1) C. E. Shannon, ``A mathematical theory of communication,'' Bell System Technical Journal, vol. 27, pp. 379-423 and 623-656, July and October, 1948
2) S. Haykin, M. Moher, "Modern Wireless Communications," Pearson Prentice Hall, 2005.

Source Coding in Practice

η = efficiency

H(S) = entropy

S = source alphabet

p_k = probability that a symbol is emitted by the source

$\overline{L}$ = bits per symbol

$$\eta = \frac{H(S)}{\overline{L}}$$

$$H(S) = \sum_{k=0}^{K-1} p_k \log_2\left(\frac{1}{p_k}\right)$$

Popular Choices of Source Codes:
Huffman, Arithmetic LZ, RLE

Channel Coding Theorem [1]

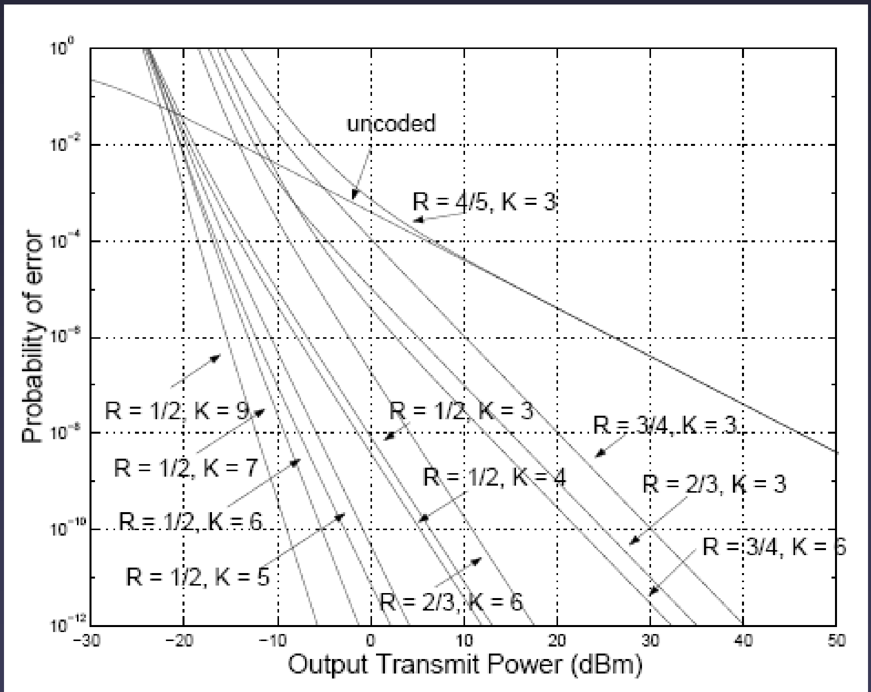
- Motivation:
  - Wireless channels are noisy
  - Reliable transmission in noisy environments requires purposeful injection of redundancy
- Channel-Coding Theorem
  - If the channel has a capacity C and the source generates information at a rate less than C, then a coding technique can produce an arbitrarily low probability of symbol error

1) C. E. Shannon, ``A mathematical theory of communication,'' Bell System Technical Journal, vol. 27, pp. 379-423 and 623-656, July and October, 1948

Channel Coding in Practice

- Channel Coding generally falls into two schemes:
  - Forward Error Correction (FEC)
    - No Feedback (Detect & Correct)
    - Block, Convolutional
  - Automatic Repeat Request (ARQ)
    - Feedback (Detect)

Convolutional Coding Performance [1]



Energy Cost of Coding [1]

$$E = P_{tx}(T_{on-tx} + T_{st}) + P_{out}T_{on-tx} + E_{dsp}^{(e)}$$
$$+ \; P_{rx}(T_{on-rx} + T_{st}) + E_{dsp}^{(d)}$$

1) E. Shih, S. Cho, N. Ickes, R. Min, A. Sinha, A. Wang, A. Chandrakasan, "Physical layer driven protocol and algorithm design for energy efficient wireless sensor networks," ACM SIGMOBILE, pp 272-286, 2001.

Information Capacity Theorem [1]

$$C = B\log_2\left(1+\frac{P}{\sigma^2}\right) bits/s$$

B = Channel Bandwidth

P = Transmit Power

σ^2 = Variance of Channel Noise

P/ σ^2 = Output SNR

- Interesting observations/implications?

1) C. E. Shannon, ``A mathematical theory of communication,'' Bell System Technical Journal, vol. 27, pp. 379-423 and 623-656, July and October, 1948

Information Capacity in Practice

$$\left(\frac{E_b}{N_0}\right)_{rx} = \frac{P_{out}}{P_{loss}\bar{\alpha}} \cdot \frac{1}{W N_{th} N_{rx}}$$

- Relating Power Consumption and Fidelity [1]
  - We can also evaluate for the expected SNR at the receiver given a general radio model
- How will the body area fading affect received SNR?
- Are there system design implications?

1) E. Shih, S. Cho, N. Ickes, R. Min, A. Sinha, A. Wang, A. Chandrakasan, "Physical layer driven protocol and algorithm design for energy efficient wireless sensor networks," ACM SIGMOBILE, pp 272-286, 2001.

Rate Distortion Theory [1]

- Motivation:
  - Alphabet of the source code is insufficient to guarantee exact source reconstruction
  - Channel (information) capacity is insufficient for the source rate
- Basic Idea:
  - Minimize information (rate) to send across a channel to approximately (distortion) reconstruct a source with a given distortion

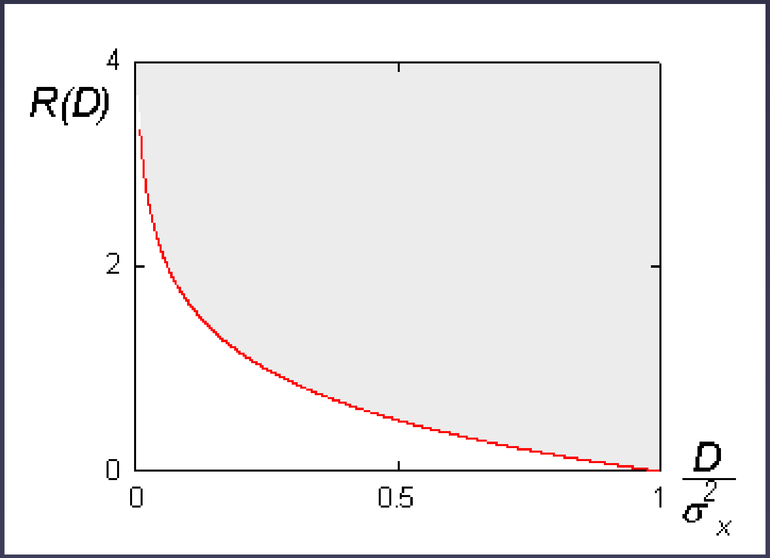
1) C. E. Shannon, ``A mathematical theory of communication,'' Bell System Technical Journal, vol. 27, pp. 379-423 and 623-656, July and October, 1948

Rate Distortion in Practice

- For a memoryless Gaussian source, R(D) is a monotonically decreasing convex function
- Pareto optimality is achieved on the rate function
- Question: What is distortion?

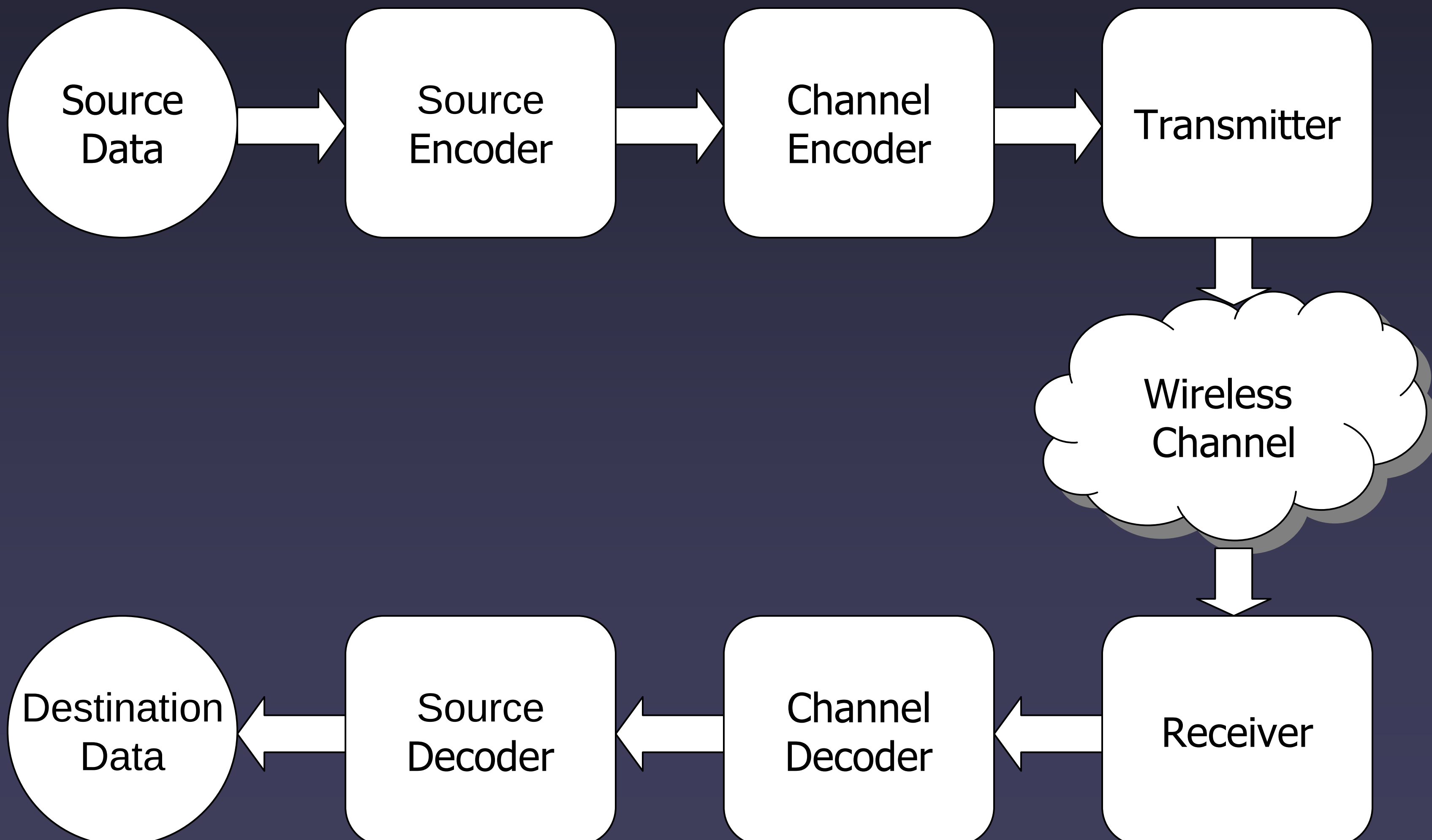
Rate Distortion for Memoryless Gaussian [1]

$$R(D) = \begin{cases} \frac{1}{2}\log_2(\sigma_x^2/D), & \text{if } D \le \sigma_x^2 \\ 0, & \text{if } D > \sigma_x^2 \end{cases}$$



1) Images from Wikimedia Commons (wikimedia.org)

Communications Perspective



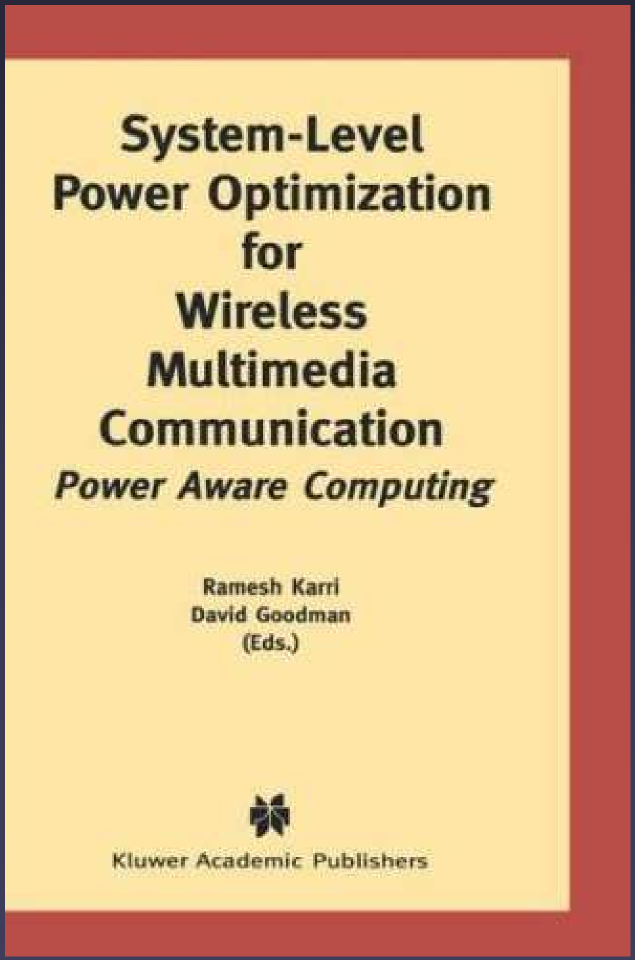
Interleaving

$$L_{burst} = R_b T_{coherence}$$

- Many channel coding schemes are designed for statistically independent, randomly distributed bit errors
- Bit errors often occur in bursts (RF-BANs)
- Interleaving scrambles the order of the channel coded source to alleviate this problem

Paper 1: Takeaway Points

Source of Paper [1]



Total Power Optimization for Wireless Multimedia Communication

~E. Erkip, X. Lu, Y. Wang, D. Goodman

1) Image from Amazon (amazon.com)

Abstract Problem Formulation

- Goal: Minimize P_{tot} subject to $D_{tot} \leq D_0$

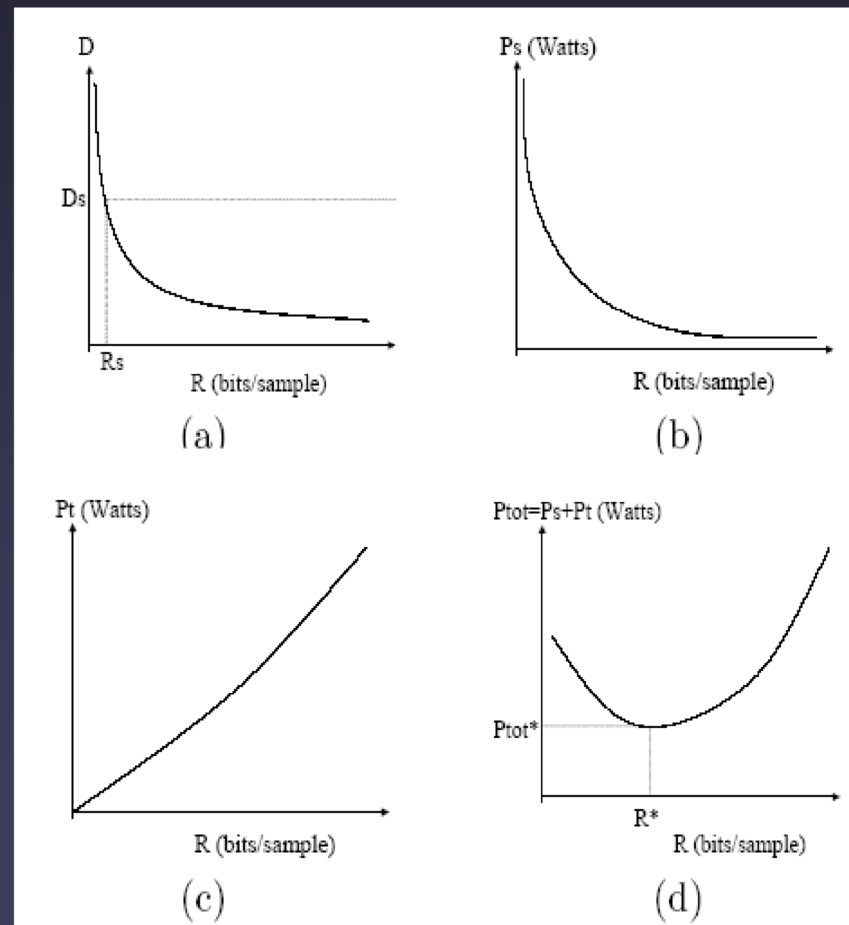
$$D_{tot} = (1 - p_s)D(R) + p_s\sigma^2$$

- Model: $P_{tot} = P_s + P_t$

$$P_{tot} = c_s f_s N + (-c_t d^\alpha R f_s N_0 \ln(2p_e))$$

- What are the knobs?
- Is this model applicable to for BANs?
- What's missing?

Rate Distortion Power Functions [1]

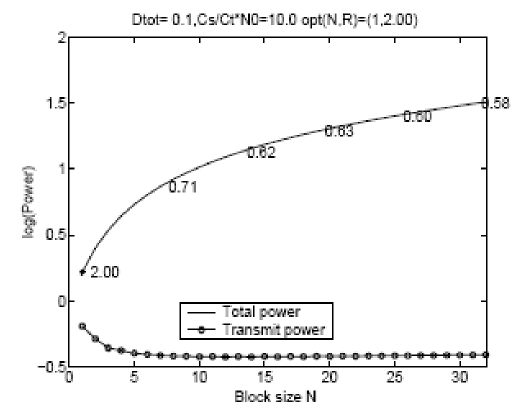


1) E. Erkip, X. Lu, Y. Wang, D. Goodman, "Total Power Optimization for Wireless Multimedia Communication," In System Level Power Optimization for Wireless Multimedia Communication, pp 1-18, 2002.

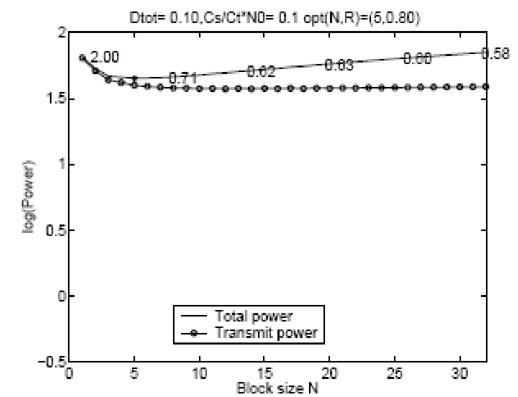
Results of Abstract Formulation

- Figure (a) models a scenario where channel attenuation is low
- Figure (b) models a scenario where channel attenuation is high

Power vs. Block Size [1]



(a)



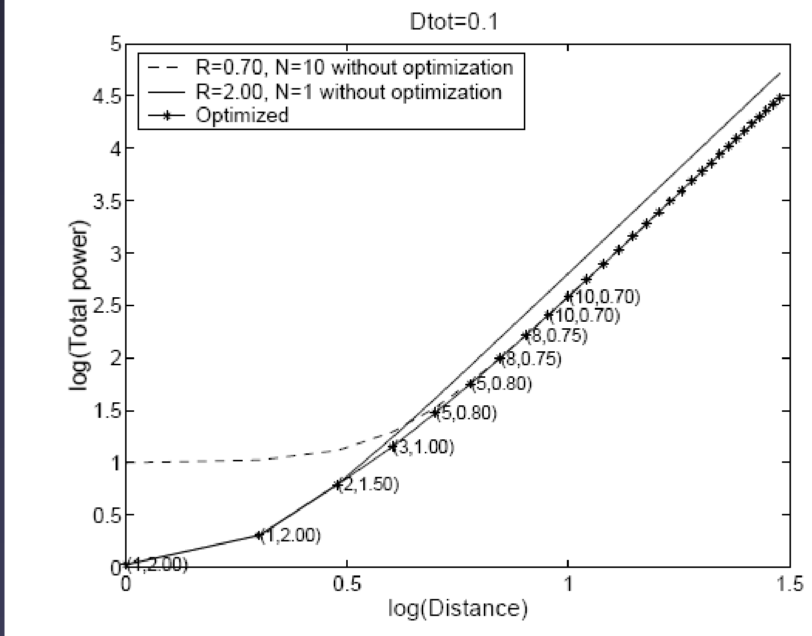
(b)

1) E. Erkip, X. Lu, Y. Wang, D. Goodman, "Total Power Optimization for Wireless Multimedia Communication," In System Level Power Optimization for Wireless Multimedia Communication, pp 1-18, 2002.

Results of Abstract Formulation

- Figure (c) summarizes minimum total power consumption vs. distance
- How do we interpret these results – especially in the context of rf-BANs?

Power vs. Distance [1]



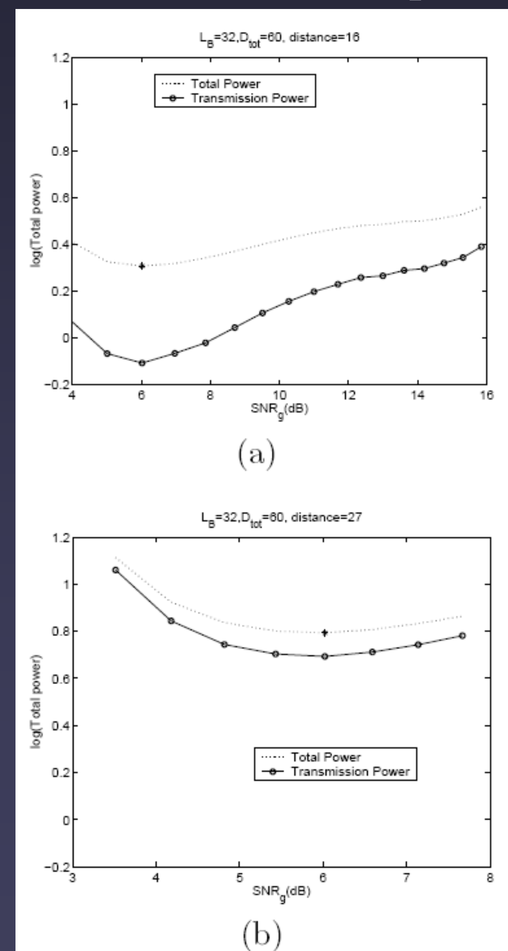
(c)

1) E. Erkip, X. Lu, Y. Wang, D. Goodman, "Total Power Optimization for Wireless Multimedia Communication," In System Level Power Optimization for Wireless Multimedia Communication, pp 1-18, 2002.

H.263 Problem Formulation

- Goal: Model H.263
- Differences:
  - Use 2 State Markov channel model
  - Assume a RS(n,k) channel code with a RS power model
  - Application power profiling (H.263)
  - Introduce burst errors

Power vs. SNR [1]



1) E. Erkip, X. Lu, Y. Wang, D. Goodman, "Total Power Optimization for Wireless Multimedia Communication," In System Level Power Optimization for Wireless Multimedia Communication, pp 1-18, 2002.

Paper 1 Conclusion

- Optimum distortion-power operating points are dependent on distance
  - Large distance transmission of each bit is more costly, so more compression and more channel coding are needed
- Is this approach realizable on resource-constrained hardware?
- How will this strategy be affected by body movement?

1) E. Erkip, X. Lu, Y. Wang, D. Goodman, "Total Power Optimization for Wireless Multimedia Communication," In System Level Power Optimization for Wireless Multimedia Communication, pp 1-18, 2002.

Paper 2: Takeaway Points

Joint Source-Channel Coding and Power Allocation for Energy Efficient Wireless Video Communications

~F. Zhai, Y. Eisenberg, N. Pappas, B. Berry, A.K. Katsaggelos

Source of Paper

- The Forty-First Annual Allerton Conference on Communication, Control, and Computing

Problem Formulation [1]

- Joint source-channel coding and power allocation
  - Increasing P_{tx} for a fixed transmission rate can decrease BER
  - Increasing P_{tx} for a fixed BER can also increase transmission rate
- Resource allocation is the primary focus
  - Minimize energy-distortion function

1) F. Zhai, Y. Eisenberg, N. Pappas, B. Berry, A.K. Katsaggelos, "Joint source-channel coding and power allocation for energy efficient wireless video ommunications," Proc of The Forty-First Annual Allerton Conference on Communication, Control, and Computing, 2003.

Minimization Problem

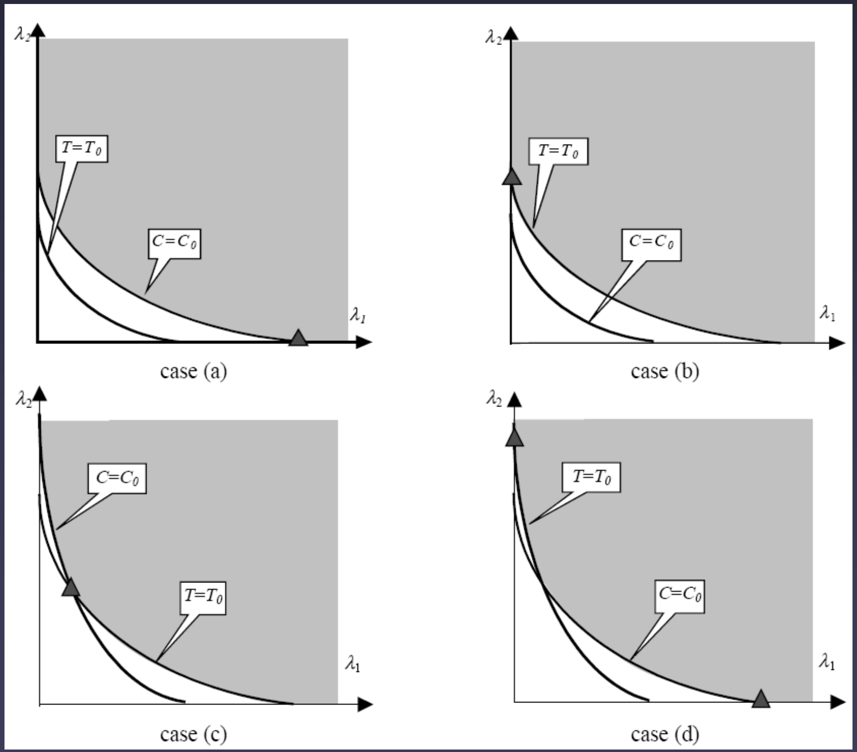
Minimization Problem 1

$$\min_{\{\boldsymbol{\mu},\boldsymbol{\nu},\boldsymbol{\eta}\in\mathcal{Q}\times\mathcal{R}\times\mathcal{P}\}} E[D] = \sum_{k=1}^{M} E[D_k(\boldsymbol{\mu},\boldsymbol{\nu},\boldsymbol{\eta})]$$

$$\text{s.t.} \quad C = \sum_{k=1}^{M} B_k(\mu_k,\nu_k)P_k(\eta_k)/R_T \leq C_0$$

$$T = \sum_{k=1}^{M} B_k(\mu_k,\nu_k)/R_T \leq T_0,$$

Cost Delay Contours 1



1) F. Zhai, Y. Eisenberg, N. Pappas, B. Berry, A.K. Katsaggelos, "Joint source-channel coding and power allocation for energy efficient wireless video ommunications," Proc of The Forty-First Annual Allerton Conference on Communication, Control, and Computing, 2003.

Paper 2 Conclusion

- Cross-layer minimization methodology for JSCCPA shows promise
  - Trades-off video quality and resource allocation for energy-efficient wireless video communication
  - Outperforms OERSC and JSCPA in simulations
- Is this type of minimization suitable for dynamic channel conditions?

1) E. Erkip, X. Lu, Y. Wang, D. Goodman, "Total Power Optimization for Wireless Multimedia Communication," In System Level Power Optimization for Wireless Multimedia Communication, pp 1-18, 2002.

Next Generation BOTE

- A communication perspective is largely neglected in current BANs
- Cross-layer analysis and design is necessary to meet application fidelity-energy requirements for next-gen BOTES

RMS Titanic [1]

1) Image under GNU License

Opportunities for Fidelity-Energy Minimization in Body Area Networks: A Communications Perspective

Mark Hanson